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into giants and dwarfs, with wide differences, not only in absolute magnitude, but perhaps also in density.

We also find important correlations of absolute magnitude with color and with the velocity of motion thru space; and finally, we learn that the stellar system represents a high degree of organization in its motions, as well as in its form and structure.

Mount Wilson Solar Observatory,
March, 1918.

THE PROBLEM OF MARS

By W. W. Campbell

The work of the great Italian astronomer, Schiaparelli, on the surface features and physical conditions of the planet *Mars*, in the years 1877-1892, may be said to constitute a unique chapter in the history of that subject. If the astronomers of today were asked to name Schiaparelli's successors in the Martian field of investigation, they would unanimously and without hesitation say Professor William H. Pickering and Professor Percival Lowell. Pickering began to observe *Mars* systematically as early as the year 1890, and he is still studying that planet, as enthusiastically as ever, from a splendid location in Jamaica. Lowell's first contribution to the subject appears to have been made in his lecture before the Boston Scientific Society, on May 22, 1894 (published in *The Boston Commonwealth* of May 24, 1894), in which he said—"The most self-evident explanation from the markings (canals) themselves is probably the true one; namely, that in them we are looking upon the result of the work of some sort of intelligent beings.* * * * The amazing blue network of *Mars* hints that one planet besides our own is actually inhabited now.* * * * We stand on the threshold of a knowledge of our closest of kin in the world of space of the most important character." Lowell went directly from the lecture room in Boston to the new observatory at Flagstaff, Arizona, and began his distinguished career as an observer of *Mars* on May 31, 1894. This career was terminated by his lamented death in 1917.

Pickering's observations of *Mars* have thus extended thru a period of twenty-seven years, and Lowell's thru a period of twenty-three years; an average of twenty-five years.

The time seems ripe for taking stock as to what these, the preeminent observers of *Mars*, accomplished in the quarter of a century. There have been other contributors to the subject, it is true, but their work in comparison with Pickering's and Lowell's has been relatively fragmentary. This statement is not intended to reflect unfavorably upon the high value of briefer researches on the planet *Mars* made by fully a dozen of their colleagues in various observatories.

It is not the intention to devote this article to my own interpretation of observations, hypotheses and theories, published by Messrs. Pickering and Lowell, but to let them speak for themselves through the medium of quotations from their papers and volumes. The method of parallel columns seems to bring the agreements and disagreements in their results more efficiently before the reader, and is employed on that account. It further seems wise to limit this inventory of results almost exclusively to the so-called canals of *Mars*, inasmuch as the canals may fairly be called the key to the solution of the Martian problems, and space is lacking for adequate treatment of the seas, lakes, polar caps, clouds, colors, and other elements.

If the quotations seem unduly numerous and repetitive, the reason lies in the sincere desire and effort to present the views of Pickering and Lowell as fully and fairly as they themselves would have cared to present them.

The passages quoted below are, with one exception, from Professor Lowell's "Mars," published by Houghton, Mifflin and Company in 1895, and his "Mars and its Canals," published by The Macmillan Company in 1906, and from Professor Pickering's "Reports on Mars," Nos. 1 to 19, which appeared in *Popular Astronomy*, from January, 1914, to January, 1918.

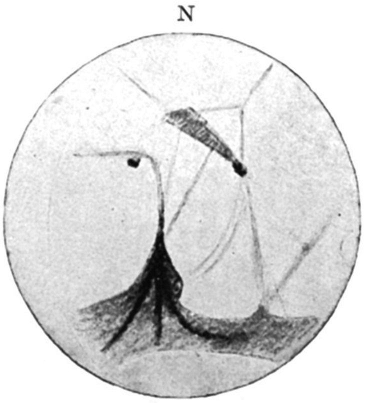

FIG. 1

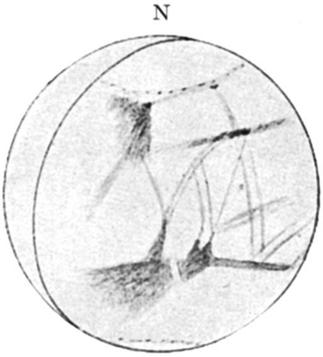

FIG. 2

PLATE V.

Figures 1 and 2 are photographic and half-tone copies of Lowell's drawings of *Mars*, from *Mars and its Canals*, pp. 126 and 229. The reader who knows his geometry will want to decide for himself whether the curved canals near the centers of the two images of *Mars*, and the straight canals nearest the lower right edges of the images, are arcs of great circles, or not. The diameter of *Mars* is approximately 4,300 miles.—W. W. C.

Quoting from Professor Lowell:

"The lines (canals) appear either absolutely straight from one end to the other, or curved in an equally uniform manner. Plotting upon a globe betrays them to be arcs of great circles almost invariably, even the few outstanding exceptions seeming to be but polygonal combinations of the same." p. 131 (1895).

"That, with very few exceptions, the lines all follow arcs of great circles is proved, first, by the fact that, when not too long, they show as straight lines; second, that, when seen near the limb, they appear curved, in keeping with the curvature of a spherical surface viewed obliquely; third, that, when the several parts of some of the longer lines are plotted upon a globe, they turn out to lie in one great circle." p. 133 (1895).

"The lines run straight throughout their course. This is absolutely true of ninety per cent of them, and practically so of the remaining ten per cent, since the latter curve in an equally symmetric manner." p. 178 (1906).

"Their length is usually great, and in cases enormous. A thousand or fifteen hundred miles may be considered about the average. * * * * Among really long ones, the Eumenides, with its continuation, the Orcus, the two being in truth one line (canal), measures 3,540 miles, * * * * throughout this whole distance, nearly equal to the diameter of the planet

Quoting from Professor Pickering:

"The statement is often made that the canals always follow the course of great circles. It is possible that this is occasionally true, but it is certain that it is by no means usually the case. The great majority that are well seen are obviously curved. Most of the remainder are either too broad or too short to make any accurate statement possible. A few others seem to be straight for a portion of their course, and a very few indeed among the fainter ones seem to exhibit no deviation for hundreds of miles. * * * * Some of the others follow for considerable distances along parallels of latitude, thus describing arcs of small circles." *Pop. Astron.*, **26**, 34, 1918.

"We see therefore that they (two canals) are fairly uniform structures 1,000 and 1,500 miles in length by 150 miles in breadth. * * * * All of the larger and more conspicuous canals are curved. The fainter ones on the other hand usually appear straight." *Idem*, **22**, 415, 1914.

"Thirdly it is thought that the public, who have been brought up to believe that the canals of Mars always appeared as straight spider lines, will be a little surprised to find that most of the representations of them show them as broad, hazy and curved bands." *Idem*, **23**, 29, 1915.

"About March 1 (1916) the character of some of the canals observed changed very markedly. Prior to that date most of them had existed as

(4,300 miles), deviating neither to the right nor to the left from the great circle upon which it set out." pp. 132-3 (1895).

broad smoothly curved lines. While many of these remained visible, there now suddenly appeared a number of new canals, very narrow, and some of them strikingly straight and artificial looking. Their advent has been foreseen (predicted) and indeed referred to in our first report, as well as in several others." *Idem*, June-July, 1916.

"That the canals are bounded by straight lines, or even smooth curves is by no means certain, indeed it is exceedingly doubtful. Such usually appears to be the case, however, owing to our insufficient optical power." *Idem*, **22**, 2, 1914.

"The lines are as fine as they are straight. As a rule they are of scarcely any perceptible breadth, seeming on the average to be less than a Martian degree, or about thirty miles wide. They differ slightly among themselves, some being a little broader than this; some a trifle finer, possibly not above fifteen miles across." p. 132 (1895).

"Each line (canal) maintains its individual width, from one end of its course to the other." p. 132 (1895).

"And the first trait that then emerges from confusion is that the markings are *lines*; not simply lines in the sense that any sufficiently narrow and continuous marking may so be called, but lines in the far more precise sense in which geometry uses the term. They are furthermore straight lines." p. 177 (1906).

"Equally striking is the uniform

"When the writer (Pickering) erected the first dome and 18-inch telescope at the Lowell Observatory in 1894, he and Professor Douglass saw the canals then exactly as they see them now (1914) as grey markings of appreciable breadth, while Professor Lowell saw them always as fine lines. It is clearly then a question of personality and interpretation of what is seen, not of instrument or atmosphere. * * * * Sometimes he (Pickering) does see the canals as fine lines, notably the canal leading to Juventae Fons (on the night of December 31, 1913), which is quite as narrow as anything drawn by Messrs. Lowell and Slipher, about 0″.05. It may be remarked incidentally that the seeing was rather inferior on that night." *Pop. Astron.*, **23**, 220, 1915.

width of each line from its beginning to its end, as it stands out there upon the disk. The line varies not in size throughout its course any more than it deviates in direction. It counterfeits a telegraph wire stretched from point to point. Like the latter seen afar, the width, too, is telegraphic. For it is not so much width as want of it that is evident." p. 179 (1906).

"Their precise width is not precisable. They show no measurable breadth and their size, therefore, admits for certain only of an outside limit." p. 180 (1906).

"Perhaps we shall not be far astray if we put one mile as the limiting width which could be perceived on Mars at present, with distance at its least and definition at its best." p. 181 (1906).

"Fifteen to twenty miles for the width of the larger of the Martian canals seems the most probable value, and two or three miles only of the more diminutive of those so far detected." p. 182 (1906).

"Doubtless both canals were arcs of large radius, but they appeared absolutely straight to the eye. The width of Protonilus was measured as we shall see later, and found to be 94 miles. Its length was 1860 miles." *Idem*, June-July, 1916.

"The canals have the following breadths: Syrtis 233 miles, Deuteronilus 194 miles, and Sabaeus 250 miles." *Idem*, Jan., 1916.

"The two dark lines connecting it with the polar cap were, with the possible exception of Cerberus, much the most strongly marked canals that we observed during this opposition. January 15 and 17 (1914) they measured some 200 miles in width, January 18 but 100 to 150. On February 4 the following one, Nilosyrtis, was but a few miles in breadth." *Idem*, **22**, 230, 1914.

"The breadth of the last (canal, Erebus) was 600 miles, that of Hades 400, but they were clearly separated by a light region which persisted, but may have been cloud. The length of these two canals was 2,000 and 1,300 miles. It might be questioned whether we could properly call such broad markings canals, but a month later their breadth was reduced about one half, and doubtless later will be reduced still further, so there seems no other course to pursue." *Idem*, **22**, 173, 1914.

"Out of the four hundred canals seen at Flagstaff, only fifty-one have at any time displayed the quality (of

"The canal may really have been double, since the observed separation is quite within the power of an 11-inch being double); that is, one-eighth roughly of the whole number observed. This point is most important; for the fact is of itself enough to disprove any optical origin for the phenomenon. The characteristic of doubling so confidently ascribed by those who have not seen it to general optical or ocular principles proves thus the exception, not the rule, with the canals, and by so doing disowns the applicability of any merely optical solution." pp. 208-9 (1906).

"Between these extremes in width (of double canals), two hundred miles more or less for the Ganges and seventy-five miles for the Djihoun, the distance parting the pairs of most of the double canals lies. From 3° to 3°.2 on the planet may be taken as that of the average;"—(that is one hundred eleven to one hundred eighteen miles.—W. W. C.) pp. 229-30 (1906).

aperture. * * * * On the other hand, my impression, recorded at the time, was that the canal was not really double, but that the effect observed was due to contrast between the dark edges of the canal and the bright background on which it is situated, which made its interior appear less dark." *Idem*, **22**, 296, 1914.

"On several occasions during the past opposition the double effect has been fairly evident here, particularly during the month of March (1916), when the canals were very narrow and often straight. Thus on March 3, seeing 9, Protonilus and Deuteronilus stretched as a strikingly straight narrow band across the disk, and the double effect was clearly seen at intervals. * * * * Once in five or ten seconds it appeared for perhaps half a second to be composed of two extremely sharp and extremely delicate parallel lines. The rest of the time it was a uniform band. One of these appearances was evidently an illusion, the question was which. For several reasons it was concluded that the brief double effect was the illusion, and the band the genuine appearance. Perhaps the most convincing argument (a) was derived from this same canal a month later, April 7, when it again took on the double appearance. Its breadth was measured at this time by means of the canal scale, and was found to be only 0".13, or 58 miles. With an 11-inch telescope even two stars must be $0''.41$ apart in order to be separated. Two dark lines require a somewhat greater separation, $0''.58$. Next (b) the two lines were separated by a space greater than either of them, such as we are all familiar with in the drawings of double canals. Such defining power is theoretically out of the question with any lens. (c) Very good seeing 8 to 10 is absolutely necessary in order to show the double effect, but with our very best seeing 11 to 12, the effect entirely vanishes.

"In *Lowell Observatory Bulletin* No. 5, Dr. Lowell explains how he observed the double canals Euphrates, Hiddekel and Gehon with a 6-inch aperture, and found the separation to be $0''.27$, $0''.26$, and $0''.28$ respectively. * * * * In order to separate a real double canal with a 6-inch aperture the separation must be at least $1''.06$. He also points out that apertures of 12 and 24 inches gave him approximately the same separation, that with the latter ranging from $0''.35$ to $0''.19$. * * * *

"To explain the effect satisfactorily has hitherto proved a very difficult matter. My impression is that it is due to a slight shifting of the image due to the air currents. Usually this shifting is more or less continuous, irregular, and rapid, producing merely a slight blurring of the image. It is believed that occasionally this shifting momentarily becomes fairly regular like a vibration, owing to the action of the atmospheric waves, and that this lasts let us say for half a second or more at a time. We shall then get two images produced side by side. Such an appearance would be visible only for extremely narrow lines, such as are found on Mars, and under such circumstances both images might be distinct even if separated by but little over 0″.1.* * * * * In this connection Dr. Lowell's remark, 'Under faulty visual conditions the doubles appear wider than they otherwise would, for some reason not easy to explain,' is of interest. Clearly that is exactly the effect we should expect to find on this hypothesis." *Idem*, June-July, 1916.

"The suggestion that the canals of Mars move over the face of the planet * * * was not movement at all but something quite different, to wit: the existence of many more canals than had till then been discovered and the varying individual visibility of each. The showing of some of these canals at one time and their apparent obliteration at a subsequent date, combined with the self-assertion of others, would result in just the apparent shift observed. This deduction was clinched by the eventual detection of both sets simultaneously." *Pop. Astron.*, **23**, 478, 1915.

"The preceding edge of the band lay nearly in the center of the disk, and was oriented precisely north and south as nearly as I could determine it. At the next presentation in November the band had swung around pointing to the southeast until it crossed the equator, when it turned and pointed southwesterly. This is precisely what it should have done if it were an atmospheric phenomenon controlled by influences that affect our trade winds." *Idem*, **22**, 94-5, 1914.

"Sometimes the canal observed does not agree either with Schiaparelli's nearest canal nor with that of Lowell, but lies between the two. * * *

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*It appears to be a new principle in optics, proposed by Pickering, that whereas "two dark lines require a separation 0″.58" to be visible in a certain telescope with perfect atmospheric conditions, the two images of one line produced by defective atmospheric conditions "might be distinct even if separated by but little over 0″.1."—W. W. C.

He (Pickering) is rather inclined to believe that some of them shift about laterally over the surface, a shift which may amount to several hundred miles." *Idem*, **22**, 172, 1914.

"The same region may one year be traversed by a single clearly marked canal running north and south, and the next year at the same season by a single canal running east and west." *Idem*, **22**, 228, 1914.

"The canals apparently traveled some 300 miles across country in about three weeks, that is at a speed of 15 miles a day. In that time they traversed their full breadth." *Idem*, **23**, 227, 1915.

"It may be thought by some that sufficient evidence has already been furnished from the work of various observers in Reports Nos. 5, 16, and elsewhere, to show that the boundaries of the dark markings, and with them the canals, are subject to a continuous gradual shift back and forth over the surface of the planet, both in latitude and longitude.

"Nevertheless the very last letter that the writer received from the late Dr. Lowell indicated doubt on his part regarding the matter. Whether he changed his mind after it was shown that his own observations furnished one of the strongest arguments in favor of such a shift, the writer does not know. It will be recalled that in 1894 Lowell found that Aryn passed the central meridian by 'the unmistakable amount of twenty minutes behind time,' 4°.8 of

"Of water we saw that the caps were undoubtedly composed, and to water, then, let loose by the melting of the cap, we may inferably ascribe the thaumaturgy in the development of the canals. * * * A quickening to vegetal growth would produce the counterpart of what we see. If, set free from the winter locking up, the water accumulated in the cap then percolated equatorward, starting vegetation in its course, this would cause the increased visibility of the canals and at the same time explain the seeming delay, by allowing for the time necessary for this vegetation to sprout. This is certainly the most satisfactory explanation of the phenomena." p. 339 (1906).

"It is, then, a system whose end and aim is the tapping of the snow-cap for the water there semi-annually let loose; then to distribute it over the planet's face." p. 373 (1906).

"Now, the water which quickens the verdure of the canals moves from the neighborhood of the pole down to the equator as the season advances. This it does, then, irrespective of gravity. No natural force propels it, and the inference is forthright and

longitude. In 1914 he found it 2°.9 ahead of its earlier position, and within 1°.0 of the position assigned to it in 1879 by Schiaparelli. * * * Other observers have found still larger deviations." *Idem*, November, 1917.

"It is not believed that the canals lie in hollowed out channels upon its surface, but rather that they are simply marshes deposited as the result of heavy rain storms occurring at night. * * * In Jamaica our tropical showers are often very heavy, and their edges very marked. The showers vary from a fraction of a mile up to several miles in diameter, and traverse the island from east to west. If instead of a rich tropical vegetation (as in Jamaica), the country presented nothing but a barren sandy plain, which we could view from a sufficient elevation, the track of each shower would appear to us as a straight, narrow, dark band of fairly uniform width. Supposing now the Martian canals to be due to this cause, let us next see what courses we should expect them to follow, for it is clear that they could not pursue a straight line for any very great distance on account of the rotation of the planet.

"On Mars * * * * there must be a belt of low pressure along the equator as in the case of the Earth, but since the atmosphere of Mars consists very largely of water vapor,

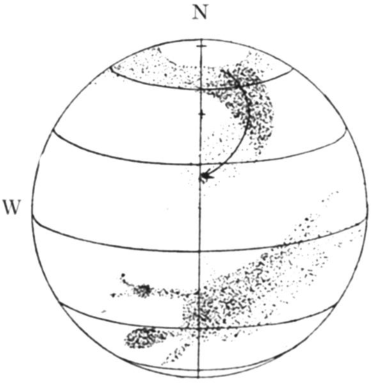

FIG. 3

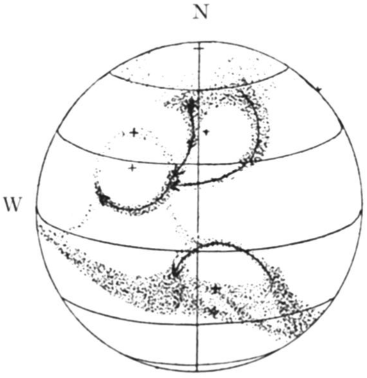

FIG. 4

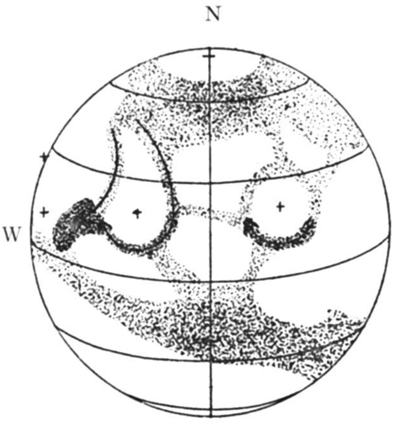

FIG. 5

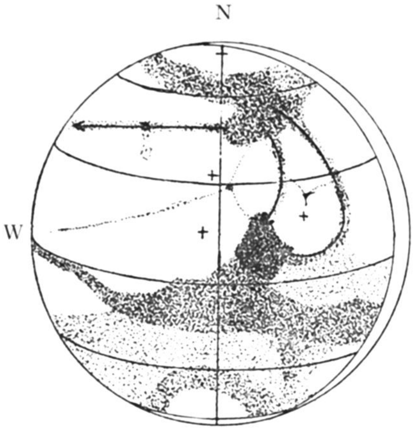

FIG. 6

PLATE VI.

Mars, by Pickering. (From *Popular Astronomy*, January, 1918.)

inevitable that it is artificially helped* to its end. There seems to be no escape from this deduction.” p. 374 (1906).

“It appears that the canal-quickening occupies fifty-two days, as evidenced by the successive vegetal darkenings to descend from latitude 72° north to latitude 0°, a journey of 2,650 miles, or 2.1 miles an hour. The rate of progression is remarkably uniform; and this abets the deduction as to assisted transference.* * * But the fact is more unnatural yet. The growth pays no regard to the equator, but proceeds across it as if it did not exist into the planet's other hemisphere. Here is something still more telling than its travel to this point. For even if we suppose, for the sake of argument, that natural forces took the water down to the equator, their action must there be certainly reversed and the equator prove a dead-line to pass which were impossible.” p. 375 (1906).

which is generated by the melting of the snow at the summer pole and removed from the atmosphere by condensation at the pole where it is winter, we must necessarily have a marked high barometer in the spring time at the pole where the vapor is generated, and marked low at the pole where it is condensed. * * * * Assuming the broad curving canals leading southward from the polar cap to be marshes fed by storms, the problem to be solved is to determine the direction of motion, * * * * On the main curving canals (as Pickering has observed them, in Figures 3, 4, 5 and 6) are drawn arcs of circles coinciding as nearly with them as possible, and from the direction of their curvature and its radius, the direction and velocity of the corresponding storm is computed.* * * *

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*Professor Lowell when he adopted it (the irrigating canal-vegetation hypothesis) suggested that the circulation was maintained by pumping. To this it is replied that that would require altogether too great an expenditure of energy, when the problem is reduced to figures. Indeed the formation of the polar caps is sufficient of itself, as Professor Douglass long ago pointed out, to show that the planetary circulation must be in large part atmospheric. * * * * If it is atmospheric in part, it might as well be wholly so.”—Pickering, *Idem*, **22**, 419, 1914.

This transfer of water from the north polar region across the equator to the agricultural regions of the southern hemisphere, and likewise from the south pole to the northern hemisphere, is “artificially helped” by “intelligent beings” on the planet, but Lowell has not ventured to tell us how.—W. W. C.

"If, now, we turn our inquiry to Mars, we shall be fairly startled at what its disk discloses. For we find ourselves confronted in the canals and oases (the junctions or crossing points of many canals) by precisely the appearances *a priori* reasoning proves should show were the planet inhabited." p. 365 (1906).

"Now, the great circle course is the shortest distance connecting two given points. The canals of Mars, then, practice this economy; they connect their terminals by the shortest, that is, other things equal, by the quickest and least wasteful path." p. 369 (1906).

"These southerly winds (in the northern hemisphere of Mars) it will be noted have a two-fold origin. They are due in part to the permanent low barometer at the equator, and in part to the melting of the northern polar cap. As the snow cap decreases in size with the advance of the season, if this latter cause is of importance, the force of these southerly currents should at first increase and then diminish in intensity, and we should therefore expect as the season advances to find the canal at first gradually shifting to the south, and then later shifting back again to the north.

"We may now briefly summarize what may be termed the 'Theory of Aerial Deposition', as applied to the broader Martian canals. As distinguished from the 'Theory of Irrigating Ditches,' * * * * the function of the canals is not to conduct the water from the northern polar cap to the southern hemisphere, where most of the vegetation is to be found, but rather to retard its transportation. Without these natural marshes or reservoirs, it is believed that the water evaporated from the summer pole would find its way too rapidly, through the natural general atmospheric circulation of the planet, to the southern polar regions, where, wrapped at this season in the long winter night and subjected to the cold of space, it would quickly be withdrawn from further use in the support of vegetal and perhaps animal

"Although each line is the arc of a great circle, the direction taken by this great circle may be any whatsoever. * * * * This indifference to direction is important as showing that the rotation of the planet has no bearing upon the inclination of the canals." p. 134 (1895).

life. * * * * The water from the melting polar cap according to this theory is deposited in the three main depressions on its border, and is then evaporated and carried by the aerial circulation of the planet along the curved lines, which in accordance with Ferrel's theory of the circulation of the winds (profoundly affected by the earth's rotation) it must necessarily follow." *Idem*, **26**, 34-46, 1918.

Quoting further from Pickering:—"With regard to the narrower or secondary type of canals, a few of which are shown in Fig. 6, it should be noted that they appear late in the season, but are then very numerous. Over 500 have been located and named at the Lowell Observatory since its foundation in 1894. The main question to be settled regarding them is as to their origin. (a) Are they artificial, as has been claimed, or (b) do they simply indicate the paths of local more or less accidental showers, or finally (c) is their uniformity and apparent straightness merely an illusion, like that of the lunar pseudo-canals, visible with an ordinary opera glass? The writer is inclined to believe that there are certain positions where these canals readily form, and certain others where they are seldom seen, and that there is a great deal still to be learned with regard to them. There is no question, however, but that they are very difficult telescopic objects, and it is probable that there are but three observatories in the world * * * * that possess the necessary combination of climate and equipment to see them distinctly. The Lowell Observatory is already definitely committed to the explanation that they are artificial, and in any case the seeing there in the early spring (Mars is nearest to the earth on March 18, 1918) is not as good as it is later, with the arrival of warm weather. It is uncertain whether the Jarry-Desloges Observatory at Setif (North Africa) will be opened this year on account of the war, but it is known that if it is, it will not have the observers and equipment that it employed in former years. Our situation (in Jamaica), although well enough equipped for the study of the broader canals, will suffer in the study of the finer ones from the smallness of our aperture (11 inches)." *Pop. Astron.*, **26**, 45-46, 1918.

It must be clear that Pickering and Lowell differ not only in their theories of *Mars*, but as to the fundamental observed facts of the canals. The theory question need not trouble us: the chief elements of both theories, that of night rains and that of vegetation along irrigating ditches, are pretty old (see *Science*, **4**, 236, 1896, col. 2 and elsewhere), and if these two theories have lived thru several decades we should not worry if they both live longer. The really serious consideration is that the canals *as observed* by Pickering and the canals *as observed* by Lowell are just about as different as two observers could make them. Both Pickering and Lowell were of the opinion each that his observing station was probably the best in the world, tho Pickering has spoken well of the Lowell Observatory and the observatory at Setif. It should be recalled that Pickering supervised the construction of the observatory at Flagstaff in 1894 and was associated with Lowell (and Douglass) at Flagstaff as an observer of *Mars* throughout the opposition of 1894. If two observers so advantageously situated, so capable and so enthusiastic as Pickering and Lowell, cannot agree better as to the basic observed facts of the Martian surface features, by virtue of studies extending thru twenty-seven and twenty-three years, respectively, what hope is there for ordinary observatories and ordinary observers to unravel the mysteries of the Martian canals?

Is it possible that anyone has been trying to see surface features on *Mars* which exceed the powers of existing telescopes and human eyes?

January, 1918.